

A Dynamical Miss: A Study of the Discrepancy Between Optical and Infrared Kinematics in Mergers

Barry Rothberg

*Naval Research Laboratory, Code 7211, 4555 Overlook Ave SW,
 Washington D.C. 20375*

Abstract. Recently, controversy has erupted over whether gas-rich spiral-spiral mergers are capable of forming m^* ellipticals. Measurements of σ_0 from the $2.29\mu\text{m}$ CO band-head for local LIRG/ULIRGs, suggest they are not. IR-bright mergers are often cited as the best candidates for forming massive ellipticals, so the recent observations have raised doubts about both the Toomre Merger Hypothesis and the fundamental assumptions of Λ -CDM galaxy formation models. However, kinematics obtained with the Calcium II Triplet at 8500 \AA suggest mergers are forming $m \geq m^*$ ellipticals. In this work, we show that kinematics derived from the CO stellar absorption band-head leads to a significant underestimation of the masses of LIRGs/ULIRGs. This is primarily due to the presence of a young population affecting CO band-head measurements.

1. Introduction

In the local universe, Luminous and Ultra-luminous Infrared Galaxies (LIRGs & ULIRGs) have long been proposed as ideal candidates for forming massive elliptical galaxies (Kormendy & Sanders 1992). They contain vast quantities of molecular gas and most show evidence of recent or ongoing merging activity, along with relatively high star-formation rates. Observations of these and other advanced mergers have long suggested that their luminosities are equivalent to or greater than massive elliptical galaxies (Schweizer 1982, 1996; Hibbard & van Gorkom 1996), and Rothberg & Joseph (2004), hereafter Paper I.

The arguments *against* LIRGs/ULIRGs, and mergers in general forming L^* or m^* elliptical galaxies are based on kinematic arguments. Until recently, kinematic studies of LIRGs/ULIRGs have used the the infrared CO stellar absorption lines at $1.6\mu\text{m}$ and $2.29\mu\text{m}$ to measure central velocity dispersions (σ_0). These stellar band-heads are prominent in late-type stars and lie within observable infrared atmospheric windows.

$\sigma_{0,\text{CO}}$'s have been previously measured for ~ 60 LIRGs/ULIRGs and two non-LIRG/ULIRG merger remnants (Doyon et al. 1994; Shier et al. 1994; Shier & Fischer 1998; James et al. 1999; Genzel et al. 2001; Tacconi et al. 2002; Dasyra et al. 2006), yielding a median $\sigma_0 \sim 150\text{ km s}^{-1}$, far less than an m^* elliptical galaxy.

Lake & Dressler (1986) used the MgIb ($\lambda \sim 5200\text{ \AA}$) and Ca II triplet ($\lambda \sim 8500\text{ \AA}$, hereafter CaT) to measure σ_0 in a sample of 13 visually selected mergers, producing a median of $\sigma_0 = 200\text{ km s}^{-1}$. Rothberg & Joseph (2006), hereafter Paper II, measured σ_0 for 38 optically selected single-nuclei merger remnants, including 10 LIRGs and 2 ULIRGs, using the CaT absorption lines

and found a median $\sigma_o = 211 \text{ km s}^{-1}$ for the entire sample and a median of 196 km s^{-1} for the LIRGs/ULIRGs.

In Paper II, K -band photometry from Paper I was combined with $\sigma_{o,\text{CaT}}$ to test whether and where merger remnants lie on the K -band Fundamental Plane (Pahre et al. 1998). Most of the merger remnants did lie on or within the scatter of the Fundamental Plane. A small number of predominantly LIRG/ULIRG remnants sat offset from the Fundamental Plane in a tail-like feature, (see Figure 1 in Paper II). The offset was due to high surface brightness ($\langle \mu_K \rangle_{\text{eff}}$), not small σ_o , suggesting the presence of a younger IR-bright population.

Paper II also demonstrated that the CO band-head produced consistently *smaller* σ_o for LIRGs/ULIRGs than CaT. This suggested previous infrared studies may have *underestimated* their masses. Unfortunately, to date, *all* published $\sigma_{o,\text{CaT}}$ and $\sigma_{o,\text{CO}}$ of remnants lie within the above-mentioned tail-like offset from the K -band Fundamental Plane, making it difficult to separate whether the discrepancy is related to galaxy properties or problems with one of the stellar lines. Silge & Gebhardt (2003) (hereafter SG03) first noted that in their sample of 25 (mostly S0) early-type galaxies, a significant fraction also showed $\sigma_{o,\text{CO}} < \sigma_{o,\text{Optical}}$. The largest discrepancies were found in S0s. They proposed that dust enshrouded stellar disks, visible only in the IR produced smaller $\sigma_{o,\text{CO}}$.

2. Sample Selection and Observations

An E0 and 6 non-LIRG/ULIRG merger remnants found to lie on the Fundamental Plane were observed in queue mode with the Gemini Near-Infrared Spectrograph (GNIRS) on Gemini-South (Program GS-2007A-Q-17, P.I. Rothberg) using the Short Camera with the 111 l/mm grating and $0''.3 \times 99''$ slit ($R \sim 6200$). Observations were centered on the $^{12}\text{CO}(2,0)$ $2.29\mu\text{m}$ band-head. Previously published optical and infrared spectroscopic data were also used (see Papers I and II for details), bringing the total to 8 non-LIRG and 6 LIRG merger remnants. All σ_o were either extracted or corrected (for data from the literature) to a $1.53 h^{-1} \text{ kpc}$ central aperture.

Low-resolution ($R \sim 1200$) spectra were obtained with SpeX on the NASA Infrared Telescope Facility for 11 merger remnants. Observations were made using the short cross-dispersed mode ($0.8\mu\text{m} < \lambda < 2.4\mu\text{m}$, $R \sim 1200$) with the $0''.5 \times 15''$ slit. These observations were used to measure Brackett γ ($\text{Br}\gamma$) equivalent widths (EW) and supplement measurement of CO indices for published $\sigma_{o,\text{CO}}$.

A comparison sample of 23 pure elliptical galaxies was assembled from the literature to look for the same discrepancy between $\sigma_{o,\text{Optical}}$ and $\sigma_{o,\text{CO}}$ observed in merger remnants and SG03. All σ_o obtained from the literature were corrected to a $1.53 h^{-1} \text{ kpc}$ aperture.

3. Comparison between Optical and Infrared σ_o

Figure 1 shows a three-panel comparison among the LIRG merger remnants (*left*), non-LIRG merger remnants (*center*) and elliptical galaxies (*right*). The data were fit with a double weighted least-squares fit to compare with a slope of unity to search for discrepancies in σ_o . Both the non-LIRG merger remnants

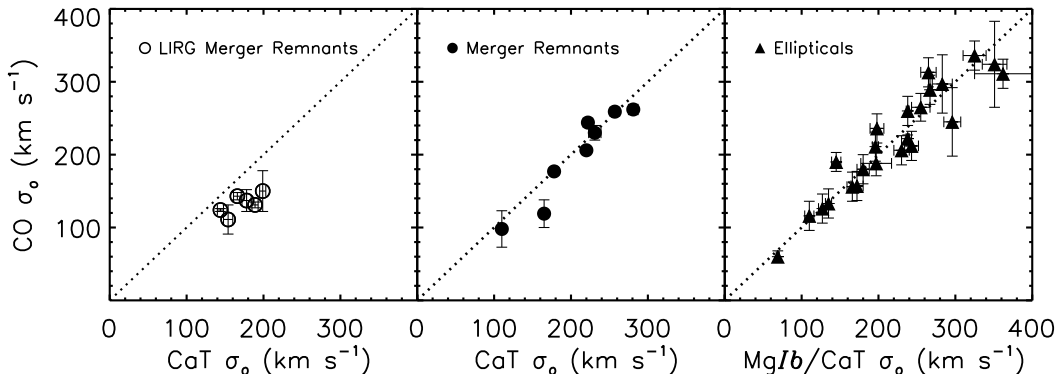


Figure 1. Comparison between $\sigma_{o,\text{Optical}}$ and $\sigma_{o,\text{CO}}$ for LIRG (*left*) and non-LIRG (*center*) merger remnants and elliptical galaxies (*right*). The over-plotted dotted line represents $\sigma_{o,\text{Optical}} = \sigma_{o,\text{CO}}$.

and the elliptical galaxies have a slope within 1σ of unity, while the the LIRG merger remnants yield a slope of 0.24 ± 0.1 .

4. σ_o Variations Compared with Stellar Populations

In Paper II it was postulated that the CaT and CO stellar features were probing two different stellar populations; the former probing older, late-type giants contributed from the progenitor spirals, and the latter sensitive to young Red Supergiants (RSGs) or Asymptotic Giant Branch (AGB) stars formed during the merger. A direct way to test this is to measure EWs of the CaT and CO features and compare those with stellar populations models in order to age-date each population. The premise is that the younger stellar populations are created within a disk formed when gas from the progenitor spirals dissipates towards the barycenter of the merger (see Barnes (2002)). At K -band, the light from this population dominates during certain epochs (Maraston 2005) (hereafter M05).

Figure 2 shows stellar population models from M05 (*solid lines*) for a simple burst population with a Salpeter IMF and solar metallicity for the CaT* and CO indices. CaT* EWs and CO_{phot} indices were measured for each merger remnant and used in conjunction with the models to age-date each remnant as plotted. In some cases, the measured indices intersected multiple points in the models. The degeneracy was broken by measuring the EW of the Paschen triplet (PaT) absorption lines (near 8500 Å) and comparing with predicted values from M05, or measuring the EWs of $\text{Br}\gamma$ emission ($2.165\mu\text{m}$) and comparing with predicted values from Starburst99 (Leitherer et al. 1999). In some cases the degeneracy for CO ages could not be broken due to the absence of $\text{Br}\gamma$. Double values are plotted in Figure 2 with a dotted line connecting them.

Overplotted in Figure 2 (*right*) next to each merger remnant are the fractional σ_o differences $(\sigma_{o,\text{CaT}} - \sigma_{o,\text{CO}})/\sigma_{o,\text{CaT}}$. The LIRG merger remnants show larger fractional differences than the non-LIRG remnants (except NGC 7252). The results in Figure 2 appear to support the premise that the presence of young populations are responsible for the smaller σ_o observed in LIRGs. The final test

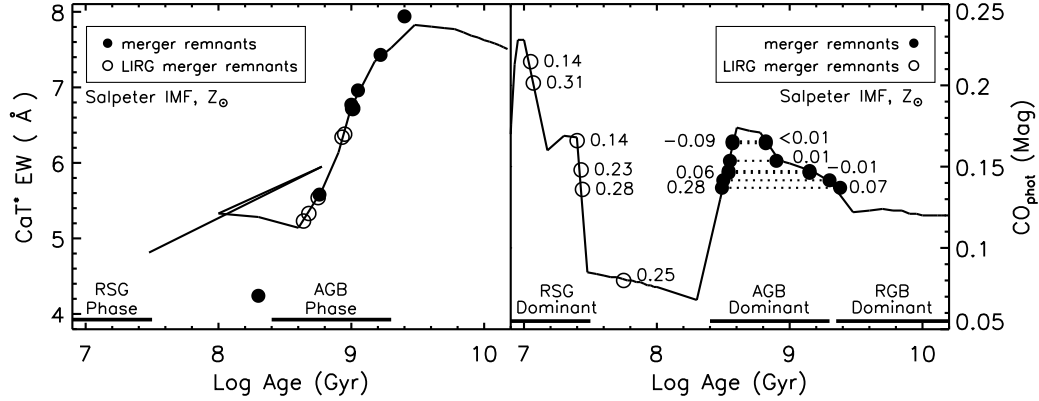


Figure 2. Stellar population models from M05 (*solid lines*) for CaT* (*left*) and CO (*right*) indices. Overplotted are 6 LIRG merger remnants (*open circles*) and 7 non-LIRG merger remnants (*filled circles*). RSG and AGB phases are noted along with when phases dominate the *K*-band light. The numbers in the right panel are $(\sigma_{o, CaT} - \sigma_{o, CO}) / \sigma_{o, CaT}$. Dotted lines indicate degenerate age results.

will be to confirm whether these young populations reside in rotating disks located within the central few kpc of the LIRG/ULIRG merger remnant using spatially resolved spectroscopic observations of the CO band-head.

References

- Barnes, J. E. 2002, MNRAS, 333, 481
- Dasyra, K. M., Tacconi, L. J., Davies, R. I., Naab, T., Genzel, R., Lutz, D., Sturm, E., Baker, A. J., Veilleux, S., Sanders, D. B., & Burkert, A. 2006, ApJ, 651, 835
- Doyon, R., Wells, M., Wright, G. S., Joseph, R. D., Nadeau, D., & James, P. A. 1994, ApJ, 437, L23
- Genzel, R., Tacconi, L. J., Rigopoulou, D., Lutz, D., & Tecza, M. 2001, ApJ, 563, 527
- Hibbard, J. E. & van Gorkom, J. H. 1996, AJ, 111, 655
- James, P., Bate, C., Wells, M., Wright, G., & Doyon, R. 1999, MNRAS, 309, 585
- Kormendy, J. & Sanders, D. B. 1992, ApJ, 390, L53
- Lake, G. & Dressler, A. 1986, ApJ, 310, 605
- Leitherer, C., Schaerer, D., Goldader, J. D., Delgado, R. M. G., Robert, C., Kune, D. F., de Mello, D. F., Devost, D., & Heckman, T. M. 1999, ApJS, 123, 3
- Maraston, C. 2005, MNRAS, 362, 799
- Pahre, M. A., de Carvalho, R. R., & Djorgovski, S. G. 1998, AJ, 116, 1606
- Rothberg, B. & Joseph, R. D. 2004, AJ, 128, 2098
- . 2006, AJ, 131, 185
- Schweizer, F. 1982, ApJ, 252, 455
- . 1996, AJ, 111, 109
- Shier, L. M., Rieke, M. J., & Rieke, G. H. 1994, ApJ, 433, L9
- Shier, L. M. & Fischer, J. 1998, ApJ, 497, 163
- Silge, J. D. & Gebhardt, K. 2003, AJ, 125, 2809
- Tacconi, L. J., Genzel, R., Lutz, D., Rigopoulou, D., Baker, A. J., Iserlohe, C., & Tecza, M. 2002, ApJ, 580, 73